Optimization of a Feedforward Symbol Timing Estimator Using Two Samples per Symbol for Optical Coherent QPSK Systems

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Abstract: A feedforward symbol timing estimator using only two samples per symbol is proposed and optimized for optical coherent QPSK signal. Simulation results are presented and discussed.

OCIS codes: (060.1660) Coherent communications; (060.4510) Optical communications

1. Introduction

Digital signal processing (DSP) enabled optical coherent system with multi-level modulation formats is considered a very promising candidate for next-generation long-haul backbone optical communications [1] since it provides very large capacity, high spectral efficiency, and easy compensation of signal distortions. Generally speaking, the clock information of signal should be restored previously so that the rest of DSP procedures can function properly. By using high-speed analog-to-digital converter (ADC), the signal after coherent detection can be either sampled synchronously with a well-controlled sampling clock usually generated by analogy means or asynchronously with a nominal sampling rate followed by fully-digital symbol timing recovery. The latter is often preferred since it relaxes constrains on the hardware such as ADC and simplifies the receiver configuration. The fully-digital symbol timing recovery is generally accomplished by firstly retrieving the information of timing error by timing phase estimation algorithms and then restoring the proper value of signal at the correct timing instant by digital interpolation.

Various timing phase estimation algorithms [2,3] have been proposed for non-data-aided feedforward schemes in the field of conventional communications and they are ported naturally to optical communications in most cases. Particularly, some of these algorithms require only two samples per symbol and consequently draw lots of attention since they are able to reduce the computational complexity in the DSP module while maintain roughly the same performance. Lee proposed a very prominent algorithm in 2002 [4], which has clear advantages over others using two or four samples per symbol. Following that, Wang et al. [5] made a modification to Lee's method to overcome the biasing problem. In this paper, Wang's method, i.e., the modified Lee's method is introduced to the coherent optical communications for the first time and optimized to be better suitable for the optical systems. Simulation results for a 28GSym/s optical coherent return-to-zero quaternary phase shift keying (RZ-QPSK) system are presented.

2. The modified Lee's estimator: simulation and discussion

The modified Lee's estimator is given by [5]

$$\hat{e} = \frac{1}{2p}\arg\left\{ g\cdot\sum_{n=1}^{2N}\left|x_n\right|^2 e^{-j(n-1)p} + \sum_{n=1}^{2N-1}\mathrm{Re}\left\{x_n^* x_{n+1}\right\} e^{-j(n-1.5)p} \right\}, \tag{1}$$

where g is a weighting factor depending on the pulse-shaping of the baseband signal, N is the number of symbols in one observed window. The true value of the normalized timing error is defined as $e = t/T \in (-0.5, 0.5]$ where τ is the symbol timing delay from the optimal timing instant and T denotes the symbol duration. The modified Lee's estimator can be further written as

$$\hat{e} = \frac{1}{2p}\arg\left\{ g\cdot\sum_{n=1}^{N}\left[\left|x_{2n-1}\right|^2 - \left|x_{2n}\right|^2\right] + j\sum_{n=1}^{N}\mathrm{Re}\left\{\left(x_{2n-1} - x_{2n+1}\right)x_{2n}^*\right\} \right\}, \tag{2}$$

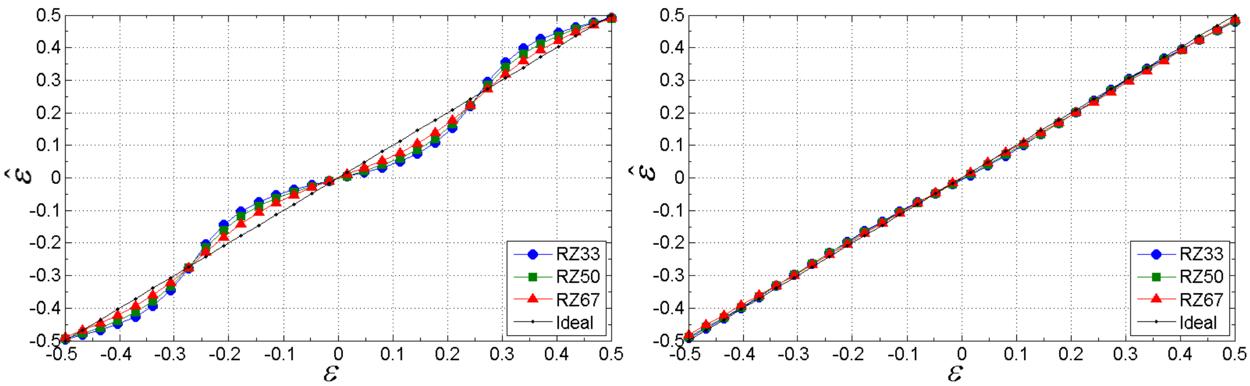
and its asymptotic mean is given by

$$e_0 = \lim_{N\to\infty} E\{\hat{e}\} = \frac{1}{2p}\arg\{g\cdot a + jb\}. \tag{3}$$

It is shown in [6] and [7], respectively, that the first term α and the second term β of this estimator have the following characteristics

$$
\begin{aligned}
a &\propto \cos(2pe) \\
b &\propto \sin(2pe).
\end{aligned}
\tag{4}
$$

Therefore, one can understand that multiplying $\boldsymbol{g}$ is simply weighting the cosine part of (3) to give a perfect tangent function of ε inside the ***arg***{} and hence an asymptotically unbiased estimation of ε can be obtained.



(a) (b)

Fig. 1. The output characteristics of (a) Lee's estimator and (b) the modified Lee's estimator for a 28GSym/s optical coherent QPSK system with various types of pulse-shaping.

Simulations are conducted to verify the performance of the proposed estimator for a 28GSym/s optical coherent RZ-QPSK system. The optical signal is generated via a IQ-modulator and detected by a polarization-diversity optical coherent receiver The ADC sampling rate is set to be two times of the symbol rate. Three common types of optical RZ pulse-shaping and no distortions except the symbol timing error are considered here. The estimator output $\hat{e}$ versus the true value of normalized timing error e is plotted in Fig.1. Each point in this figure is a result averaged over 512 symbols, i.e., the block-size N equals 512 for feedforward estimation in (1) and (2). The outputs of Lee's and the modified Lee's estimator are shown in Fig.1 (a) and (b), respectively. One can see that the estimation bias is evident for Lee's estimator and it tends to increase with the decreasing duty-cycle of the optical pulses. In comparison, the bias disappears for all kinds of RZ shapes when using the modified estimator.

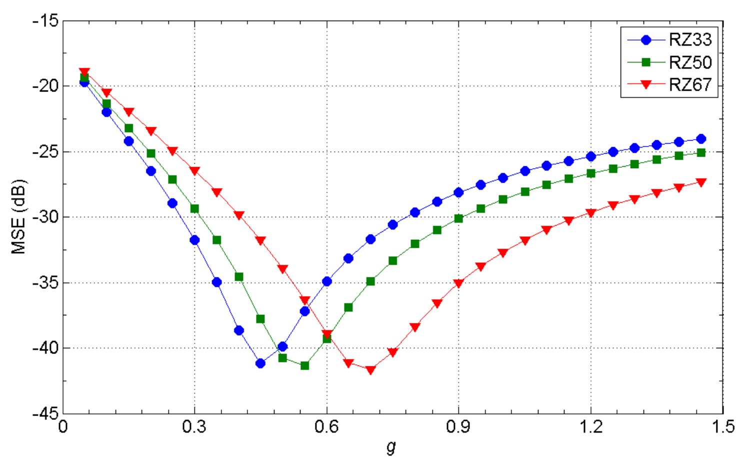


Fig. 2. The estimation error versus the weighting factor g for a 28GSym/s optical coherent QPSK system with various types of pulse-shaping.

Note that the optimal values of $\boldsymbol{g}$ are chosen by searching to give the minimum estimation error between the estimated and true values of e in Fig.1 (b). These optimal factors are also found to be deterministic for a certain pulse shape, which is depicted in Fig.2. Block-size of 512 symbols are utilized to calculate the estimation mean-squared-error (MSE) of the modified Lee's method. The MSE is defined as

$$\text{MSE}_1 = E\left[\left(\hat{e}_i - e_i\right)^2\right], \tag{5}$$

where $e_i = i/L$, $i = -L/2 \ldots L/2$ and $\hat{e}$ is the estimation of e . L is set to be 32 for the MSE_1 estimation in the simulation. From this figure, distinct MSE minimums can be observed in the curves at points of g = 0.45, 0.54, and 0.69 for pulse shapes of RZ33, RZ50, and RZ67, respectively. A larger L and smaller step of searching will provide much more accurate read of these values if desired. These weighting factors should be therefore considered optimal and consequently adopted by systems using the corresponding pulse-shaping.

Then the averaged MSE versus optical signal-to-noise ratio (OSNR) for various feedforward block-size N is investigated through simulation. The averaged MSE is defined as

$$\text{MSE}_2 = E\left[\text{MSE}_1\right], \tag{6}$$

where 300 independent simulation trials for MSE_1 calculation are carried out and the results are further averaged to estimate MSE_2 in the simulation. Optimal g mentioned above is chosen to have the estimator working at its maximum performance. The results are shown in Fig.3. It can be observed that the MSE performance is similar for various types of pulse-shaping and larger block-size provides more accurate and ASE-insensitive estimation. The MSE decreases with higher ONSR though it eventually reaches an error floor for all cases.

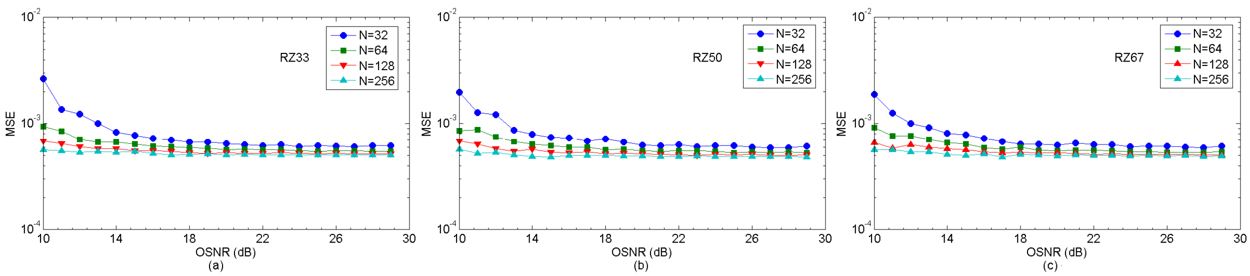


Fig. 3. MSE_2 as a function of OSNR for pulse-shaping of (a) RZ33, (b) RZ50, and (c) RZ67. The block-size N is scaling from 32 to 256. The MSE decreases with higher OSNR value though error floor appears eventually.

3. Conclusions

In this paper, a novel feedforward symbol timing estimator is proposed and optimized for the prevalent optical coherent communications. The optimal weighting factors are found through simulations for a 28GSym/s optical coherent QPSK system with various types of RZ pulse-shaping. Simulation results are also presented here to show the good performance of the proposed algorithm.

4. References

[1] S. J. Savory, “Digital Coherent Optical Receivers: Algorithms and Subsystems,” ***IEEE J. Sel. Topics Quant. Electron.***, vol. 16, no. 5, pp. 1164-1179 (2010).

[2] E. Panayirci and E. Y. Bar-Ness, “A new approach for evaluating the performance of a symbol timing recovery system employing a general type of nonlinearity,” ***IEEE Trans. Commun.***, vol. 44, no. 1, pp. 29–33 (1996).

[3] M. Morelli, A. N. D’Andrea, and U. Mengali, “Feedforward ML-based timing estimation with PSK signals,” ***IEEE Commun. Lett.***, vol. 1, no. 3, pp.80–82 (1997).

[4] S. J. Lee, “A new non-data-aided feedforward symbol timing estimator using two samples per symbol”, ***IEEE Commun. Lett.***, vol. 6, no. 5, pp. 205–207 (2002).

[5] Y. Wang, E. Serpedin, and P. Ciblat, “An alternative blind feedforward symbol timing estimator using two samples per symbol”, ***IEEE Trans. Commun.***, vol. 51, no. 9, pp. 1451–1455 (2003).

[6] M. Flohberger, W. Gappmair, S. Cioni, "Two iterative algorithms for blind symbol timing estimation of M-PSK signals," ***International Workshop on Satellite and Space Communications*** (***IWSSC***) 2009, pp.8-12 (2009).

[7] F. M. Gardner, “A BPSK/QPSK timing-error detector for sampled receivers,” ***IEEE Trans. Commun.***, vol. COM-34, no. 5, pp. 423–429 (1986).